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THE FUNCTION OF A NATIONAL PHYSICAL LABORATORY

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1. Every modern industrial country has found it essential to set up one or more laboratories under government control covering certain areas in the physical sciences which are neither the responsibility of the universities nor of industry. The most obvious area is that of precise measurement in order to provide a sound scientific basis for legal standards of weights and measures. A second responsibility of such laboratories is to provide an independent and impartial authority for the testing of measuring instruments of all kinds used not only by government but also by industry, by universities and research institutions, and even by the general public. The third main responsibility is to encourage and, where necessary, to pioneer the application of advances in pure physics to urgent national technological and industrial problems. This last responsibility is a very wide one and it cannot be sharply defined since industry must carry a large share of this responsibility itself if it is to be progressive and self reliant. Nevertheless there are certain areas and problems which are best tackled by national laboratories under government control, rather than by individual firms or manufacturing industries. This is particularly true when the capital investment is very large in the pioneering stages, or when the government laboratory has special expertise in the new field, or when government must maintain control of the new development for political or other reasons.

2. No two countries have tackled these problems in quite the same way but there are certain features common to nearly all the schemes of organisation. It would be surprising if the under-developed countries found it possible to make industrial progress under a completely different pattern. Thus every country has found it essential to have some form of standards laboratory to fulfil the needs of legal metrology. In general, the ultimate authority for testing instruments is vested in the same laboratory, although the actual testing may be carried out in a number of laboratories situated in various parts of the country. Germany and the USSR have practised such de-centralisation of instrument testing, whereas in Britain the general policy has been to devolve a good deal of the responsibility for testing against secondary standards to industry or to semi-government organisations (e.g. the British Standards Institution or the Research Associations of the Department of Scientific and Industrial Research) leaving the National Physical Laboratory mainly with the responsibility of verifying secondary standards against primary standards.

3. It is in the third responsibility, i.e. of pioneering the application of physics to industry, that the greatest divergences occur. This is not surprising when one considers the magnitude of the problem. Even here there is one feature common to all countries, viz. the establishment of quite

separate laboratories and organisations to deal with the applications of atomic energy for industrial purposes. The magnitude of the effort required in this field is such that it clearly demands a separate organisation, quite apart from its close connexion with defence policy. Although the atomic energy laboratories logically belong to any system of national physical laboratories it has become conventional to confine the use of the term National Physical Laboratory to non-nuclear physics and we shall do so in this paper. There is, however, one important aspect of nuclear physics which is the concern of the national standards laboratories, viz. standards of measurement in the field of high energy ionising radiation and nuclear particles. Since the measurement of radioactive fall-out and the standardisation of radioactive isotopes used in medicine and industry will be one of the first needs of an under-developed country whereas the development of atomic energy will come at a later stage, nuclear physics might well be incorporated with non-nuclear physics in a single national physical laboratory in the initial stages of development.

4. Atomic energy is not the only field where it pays to pioneer the industrial development in government laboratories. Many countries have found it essential to set up government or semi-government laboratories for subjects such as aerodynamics, ship hydrodynamics and metallurgy. In Britain these laboratories form part of the National Physical Laboratory, whereas in Germany, France, Sweden and the United States the corresponding laboratories are not associated with the standards laboratories. On the other hand, radio wave propagation is dealt with in the USA by a branch of the National Bureau of Standards, whereas in Britain what was the Radio Division of the National Physical Laboratory has now become the Radio Research Station, an independent government research laboratory. Such differences are inevitable and arise partly from local conditions and accidents of growth. The fact is that a national physical laboratory must be a complex of laboratories if it is to be useful to industry. In Britain this complex is largely on one site under a single director. In most other countries the standards and testing organisations are separate institutions both physically and administratively. It is for this reason that I shall use the National Physical Laboratory to illustrate many of the points I wish to make about the function of a national physical laboratory with special reference to under-developed areas. Although as industrialisation proceeds, each under-developed country will create the organisation most suited to its needs, it will almost certainly be forced to start with a single laboratory which is likely to have to cover much the same wide ground as the NPL did in the first decades of its existence.

Legal Standards

5. There are two distinct aspects of the standards problem, viz. the legal and the industrial. A legal system of weights and measures is essential for any form of trading whether it be national or international. That system must be based on sound physical principles so that the standards are as nearly immutable as the physicist can make them. Thus the metre is now defined in terms of the wavelength of light - a natural atomic constant. But the Imperial Standard Yard (the legal standard of length in Britain since 1855) is based on the distance between two marks on a metal bar. It has been shown that this distance is contracting by one part in a million every 30 years and this standard will have to be replaced. Until quite recently the yard and the pound as legally defined in Britain, Canada and USA were slightly different. This difference was originally not a serious matter but it was beginning to be awkward in very precise mechanical engineering. It was therefore necessary for the standards laboratories in the countries where the yard/pound system was legal to come to an agreement on an "international" yard and an "international" pound. In order to ensure maximum compatibility with countries using the

metre system, the international yard and the international pound have been defined in terms of the metre and of the kilogram. It is hoped that the international yard will be legalised in Britain in the near future. It has already been legalised in a number of the other countries using the yard/pound system.

6. It might be argued that emergent countries will all adopt the metric system and so avoid the kind of problem just discussed. This is a political question which is outside the scope of this paper but even if a country adopts the metric system, it does not thereby want to trade only with other countries using the metric system. Thus, problems concerned with the compatibility of the two systems will arise no matter which system is chosen and expert advice from a national standards laboratory will be required to resolve them.

7. This raises the question whether the national standards laboratory should have the responsibility for the legal side of metrology. In Britain the legal side of metrology is the concern of the Board of Trade which receives expert scientific advice and guidance from the National Physical Laboratory. In Germany, the Physikalische-Technische Bundesanstalt, and in the USA, the National Bureau of Standards, have responsibility for the legal as well as the scientific side of metrology. What is important is that it should be possible to introduce improvements into the legal definitions of the various units of length, mass, time, power, etc. without involving these quantities in all the relevant trade legislation. It is this unfortunate conjunction which has delayed the legalisation of the international pound in Britain.

8. In addition to the legal side of metrology concerned with trade and commerce, certain legal standards of physical quantities are required to protect the safety and health of the individual. Especially important is protection from radiological hazards in the handling of radioactive materials and X-ray and other equipment in medicine and industry. As a country becomes industrialised one of the unfortunate consequences is the increase in noise, frequently to an almost intolerable level. Yet comparatively few countries have found it feasible to introduce a legal definition of noise based on the readings of some form of noise meter. The difficulty here is that noise is a subjective concept and can only be related to the intensity of a sound wave in a somewhat arbitrary and empirical manner. Just as individuals differ in what they consider to be an unpleasant noise so nations will wish to set their own legal standards for noise. In order to make such standards as impartial as possible their national standards laboratory must have a section devoted to problems in acoustics. The provision of adequate safety factors in the construction of bridges, dams and tall buildings requires expert guidance from aerodynamicists and hydrodynamicists as well as from engineers.

Industrial Standards and Testing

9. The provision of a government laboratory to which industry can refer for the calibration of its secondary standards against the definitive primary national and international standards is so obvious that it is unnecessary to labour this point. Even when an under-developed country has only a small degree of industrialisation, it may find that it is advantageous to be able to check the quality and specification of imported equipment and material in its own laboratories. Moreover, importers may need expert advice in laying down certain of the physical specifications which should be incorporated in the order for the equipment. It might be argued that imported equipment could be guaranteed by the national laboratory of the country from which it is being imported. This is only feasible for a very limited number of exceptionally high quality measuring instruments. It has to be remembered also that any such guarantee applies to the time at which the test was made. Instruments

can deteriorate in certain climatic conditions or can be rendered inaccurate through misuse. To have to refer all such problems to a foreign country would not be a satisfactory state of affairs.

10. Accurate measurement is so basic to all technology that a central laboratory with a group of experts in the science of metrology is vital to technological development in all fields whether industrial, medical or agricultural. New problems of measurement are always arising and many of them are common to quite different branches of technology. It would be a misuse of the limited scientific effort available in most under-developed countries to create expert groups on measurement in the various technologies. Undoubtedly as industrialisation proceeds and the number of trained scientists and technologists increases, some of the larger organisations will develop their own metrological groups but a central authoritative laboratory will always be required by the smaller firms and organisations. The central standards laboratory will of course engage on research in metrology, continually improving methods of measurement and maintaining contact with research in metrology in other countries.

11. The testing of equipment and of instruments may range all the way from being a routine operation which can be carried out by junior technicians to being a research project which demands the attention of a highly qualified scientist. It will usually be advantageous to segregate the routine testing into a separate laboratory but to leave the high grade test work in the standards laboratory. There will tend to be a steady movement of some of the test work from the standards laboratory to the testing laboratory and even to industry. Thus a new problem in measurement is usually referred to the standards laboratory which may develop a prototype instrument. This instrument may go directly into industrial production and use or it may require to be checked by the testing laboratory during an intermediate period. Instruments which are being used in connection with governmental regulations may continue to be tested indefinitely by the testing laboratory.

International Co-operation

12. Any newly established State planning to set up a national weights and measures authority or standards laboratory would be well advised to join the two international weights and measures organisations, the one concerned with scientific, and the other with legal, aspects of metrology.

13. The first, established in 1875 by international treaty (Convention du Mètre) and having a present membership of 38 States, is responsible for fundamental scientific metrology and especially the maintenance and improvement of the metric units and standards of measurement. It operates through the Conférence Générale de Poids et Mesures consisting of delegates from the Member-States, meeting every six years, and an elected executive committee of 18 members, the Comité International des Poids et Mesures, meeting every two years, having the assistance of a number of specialist advisory committees (Comités Consultatives). There is also a central laboratory and office, the Bureau International des Poids et Mesures, situated at the Pavillon de Breteuil, Sèvres, near Paris. The annual subvention for maintenance is provided by subscriptions from the Member-States calculated on the basis of national income in the same way as for United Nations' agencies.

14. The second, established in 1955 by a similar kind of international convention, and having a present membership of 33 States, is known as the Organisation Internationale de Métrologie Légale (International Organisation of Legal Metrology). It has a similar structure to that of the scientific

organisation and is charged with (a) maintenance of a central documentation and information service concerning measuring instruments, the legal requirements relating to them and the departments which test them; (b) the establishment of model regulations in respect of the use and control of measuring instruments; (c) determination of the necessary characteristics and qualities of measuring instruments to enable international use to be recommended. There is no central laboratory; the central office is the Bureau International de Métrologie Légale, 9 Avenue Franco-Russe, Paris VII^{e}. Annual subscriptions from the Member-States are calculated on a population basis, but are quite modest.

15. By joining these organisations a newly established State would immediately have at its disposal the experience of experts in other States in setting up and operating weights and measures authorities and standards laboratories.

More General Responsibilities

16. It was suggested earlier in this paper that in the initial stages of industrial development, a country will have to make its national physical laboratory carry very wide responsibilities in much the same way as the National Physical Laboratory did in Britain during its early years. When the National Physical Laboratory was founded in 1900 it had a staff of about 25 and had two divisions, viz. physics and engineering. It now has a staff of over 1300 organised into the following ten Divisions, viz. Standards, Light, Applied Physics, Basic Physics, Mathematics, Autonomics, Metallurgy, Aerodynamics, Ship Hydrodynamics and Administration (including central services). It should also be mentioned that about ten years ago the Radio and Engineering Divisions were split off to become independent government laboratories (the Radio Research Station and the National Engineering Laboratory) with a combined staff of 835 in separate locations. Moreover, certain of the problems now dealt with by the independent Building Research Station, the Road Research Laboratory and the Hydraulics Research Laboratory were handled by the National Physical Laboratory before these laboratories were set up in 1926, 1933 and 1951 respectively. This brief outline of the past and present responsibilities of the National Physical Laboratory in no way implies that it should be copied by any country making a fresh start on the problem of how best to back its industrial development by one or more government laboratories. Indeed, it is most important to plan carefully and to benefit from the past experience of others, for once the capital expenditure has been made on large laboratories it is a major undertaking to move even part of them to new locations.

17. As a minimum, any new national physical laboratory should cover the classical branches of physics such as heat, optics, acoustics and the more modern branches such as atomic physics, radiology and electronics. It must also cover the mechanical properties of materials and indeed it is difficult to see how it can avoid covering certain parts of mechanical engineering. Similarly it must cover electrotechnics in connexion with the requirements of the system of electric power, whether the latter is run by the state or by private enterprise. In most of these subjects the work will overlap that carried out on standards, e.g. there is no need to have separate laboratories for the standards work on heat and the industrial work on heat when the number of scientists is limited and facilities are also limited as they must be in the early stages of development. Indeed there is much to be said for keeping the standards work and the industrial work together permanently.

18. If a country has any metallurgical industry it would be wise to have a central metallurgical laboratory. It is not essential for this to be part of the national physical laboratory (as it is in Britain) but it would be

advantageous to have it in close proximity to that laboratory. Metals and materials made of metal require to have their fracture, creep, fatigue and ductility investigated in a very scientific manner. Their electrical and magnetic properties (especially when alloyed with other metals or when carefully controlled quantities of known impurities have been added) can be of great economic importance. Methods of extreme purification and standards of purity may have to be investigated. This demands highly sophisticated physical and chemical techniques. This last point raises the question of a national chemical laboratory. In Britain the National Chemical Laboratory adjoins the National Physical Laboratory and each is a great help and convenience to its neighbour. The National Bureau of Standards has a chemical division and no adjoining laboratory. Whether any national chemical laboratory is administratively part of the complex of national physical laboratories or not is unimportant so long as the physicists in the national physical laboratory have close at hand a first rate chemical laboratory.

19. The use of electronic computers in industry is growing very rapidly and automation generally is vital if an industry is to remain competitive while giving its workers a reasonable standard of living. It follows that either within or alongside any national physical laboratory there should be a laboratory for research and some development work on computers and automation. In the National Physical Laboratory this is the responsibility of the Autonomics Division. In addition to carrying out research on methods of improving the speed and efficiency of computers this laboratory is trying to devise machines which will replace human beings in tasks such as the recognition of numerals and letters, translation from one language to another and the retrieval of information. Another of its objectives is to devise equipment which will enable certain industrial processes to be run by self-adaptive control, i.e. when some condition changes and an adjustment has to be made, the equipment will adapt itself to the new circumstances by rapid trial and error of various possible adjustments. Of course such sophisticated research as this last one, will not be done in under-developed countries for several years, but there are many simpler problems of automation which should be studied in almost any industry. Moreover, special purpose small computers require to be devised for particular problems. Imported computers have to be maintained and improved by the addition of ancillary equipment.

20. Equally important is the most efficient use of computers. Computers are expensive in capital cost and in maintenance. It is essential that the programmes for their operation should be devised with as much ingenuity as possible to economise on computer time. This requires trained mathematicians and so it would be wise to associate a group of mathematicians with the centre for research on computers and automation. In the National Physical Laboratory a whole division is devoted to Mathematics but it contains a sizable group of theoretical physicists who can help with the theoretical side of the work done in some of the other divisions. There is no doubt that some mathematicians and theoretical physicists are required in any form of national physical laboratory. Local conditions will usually determine their distribution and organisation.

21. Any country which expects to build its own ships will require to have a towing tank in which to test the hull models and possibly a water tunnel to study certain problems in the design of propellers. These problems are handled by the Ship Division of the National Physical Laboratory in Britain. In other shipbuilding countries this kind of work is done either in conjunction with the corresponding naval work or in semi-commercial establishments. However there is at present so much excess capacity for shipbuilding all over the world that it is unlikely that any under-developed country will find it

an economic proposition to build its own ships for some years to come.

22. On the other hand, there may well be urgent problems in hydraulic engineering which require study by experts, e.g. flood control, harbour and coastal protection. Some of this work was done by the National Physical Laboratory in the early years of its existence. It was found essential to set up a separate Hydraulics Research Station. Although the expert advice required on hydraulics can usually be provided by one of the more advanced countries, some consideration should be given to the provision of a national hydraulics laboratory which might well be sited near the national physical laboratory.

23. Air transport and air defence will certainly loom large in the industrial development of a new country. Consideration should be given to the establishment of a laboratory for aeronautical research. Unfortunately this is a very expensive field of research, since the wind tunnels and associated equipment mean not only a large initial outlay of capital but demand continual modification and modernisation. However, if attention is restricted to the civilian and industrial applications of aerodynamics, as opposed to military requirements, the initial outlay and cost of maintenance might be well worth while in countries where very high winds are a frequent source of danger to civilian property.

24. Although it seldom forms part of a national physical laboratory, some form of meteorological laboratory will be essential in connexion with weather forecasting and weather recording. Although it is still some way from being an exact science, weather forecasting is becoming much more reliable, and the more information that is available the more detailed and accurate is the forecast likely to be.

General Conclusions

25. An under-developed country which is embarking on a programme for the technological development of its resources would benefit enormously from the creation of a national physical laboratory which should be envisaged as developing into a complex of laboratories over a period of about 20 years.

26. This laboratory should initially provide facilities for scientific work in the following fields:-

Standards of mass, length, time, heat, sound, radiation of all types, and of all electrical and magnetic quantities
Electrotechnics
Mechanical properties of metals and non metals
Testing and calibration of measuring instruments
Atomic Physics and Electronics
Meteorological studies.

27. The national physical laboratory should be integrated with the national weights and measures authority and should join the two international organisations for scientific and legal metrology.

28. At the earliest opportunity and depending on the local circumstances and needs, provision should also be made for scientific work in

Metallurgy
Automation and Computers
Hydraulics
Industrial Aerodynamics
Ship Hydrodynamics

29. Some of the work done in such laboratories will overlap partly with that done in industry and at the universities. There is no harm in such an overlap provided care is taken that needless duplication is avoided. It is only by having some overlap that such an institution can have good contact with industry, which it is serving and with the universities, from which it must continually recruit its staff. The easy movement of some staff to and from industry and to and from the universities would be of great benefit to all parties. In the majority of the highly developed countries this movement is all too rare because conditions of employment, pension schemes, etc. have become set into different patterns in these three areas. Although the under-developed countries are starting late in the technological race they can catch up more quickly by learning from the mistakes made in the industrial development of the more advanced countries.

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